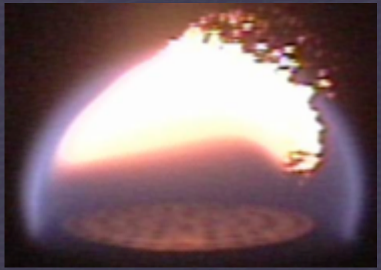
A Burning Rate Emulator (BRE) for Study in Microgravity



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Objective & proof of concept

- Seek to emulate the steady burning conditions of condensed fuels by using a gas burner.

Method

- **Hypotheses: Burner matches properties**

1. **heat of gasification** *by flow rate and heat flux measurements*
2. **heat of combustion** *by a mixture of gaseous fuel and diluent*
3. **surface re-radiation** *by temperature measurement*
4. **smoke point** *by fuel - diluent mixture.*

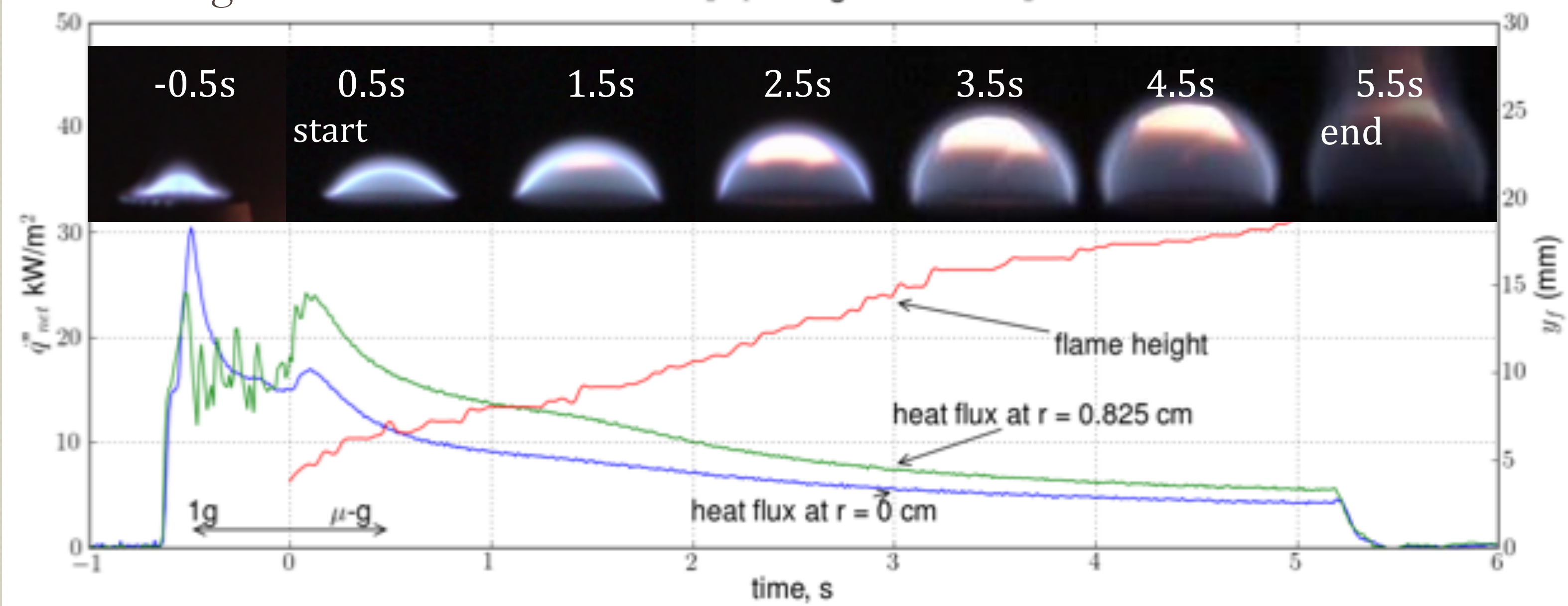
Tests: NASA 5.18 s

- About 53 tests Varying:
  - Diameter: 25, 50 mm
  - Fuel: CH_4, C_2H_4 w & wo N_2
  - Flow rate 3.5 to 12.7 g/m^2s
  - Pressure 0.5 to 1 atm
  - Oxygen 21 to 30%
- Fix heat of combustion
- & smoke point
- Obtain L and Ts

Symbol	Gas	Burning rate (g/m^2-s)	X_{O2}	P (atm)	Δh_c (kJ/g)	SP (mm)
○	100% CH_4	9.05	30%	1	49.6	∞
○	100% CH_4	6.67	30%	1	49.6	∞
◉	100% CH_4	6.67	21%	1	49.6	∞
○	100% CH_4	6.67	30%	1	49.6	∞
○	100% CH_4	12.71	30%	1	49.6	∞
○	100% CH_4	4.72	30%	1	49.6	∞
○	100% CH_4	12.71	30%	1	49.6	∞
○	100% CH_4	9.05	30%	1	49.6	∞
●	100% C_2H_4	6.02	21%	1	41.5	120
●	100% C_2H_4	6.02	21%	1	41.5	120
●	100% C_2H_4	4.63	21%	1	41.5	120
●	100% C_2H_4	3.48	21%	1	41.5	120
▣	100% C_2H_4	3.48	30%	1	41.5	NA
■	100% C_2H_4	3.48	30%	0.7	41.5	NA
▲	100% C_2H_4	3.48	26%	0.81	41.5	NA
△	100% C_2H_4	3.48	26%	1	41.5	NA
□	100% C_2H_4	3.48	30%	0.5	41.5	NA
□	100% C_2H_4	3.48	30%	0.5	41.5	NA
◆	50% C_2H_4	6.95	21%	1	20.8	240
◇	50% C_2H_4	6.95	26%	1	20.8	NA
◇	50% C_2H_4	6.95	26%	1	20.8	NA
◇	50% C_2H_4	6.95	26%	0.81	20.8	NA
◆	50% C_2H_4	9.26	21%	1	20.8	240
◇	50% C_2H_4	9.26	26%	0.81	20.8	NA

Typical Results 25 mm

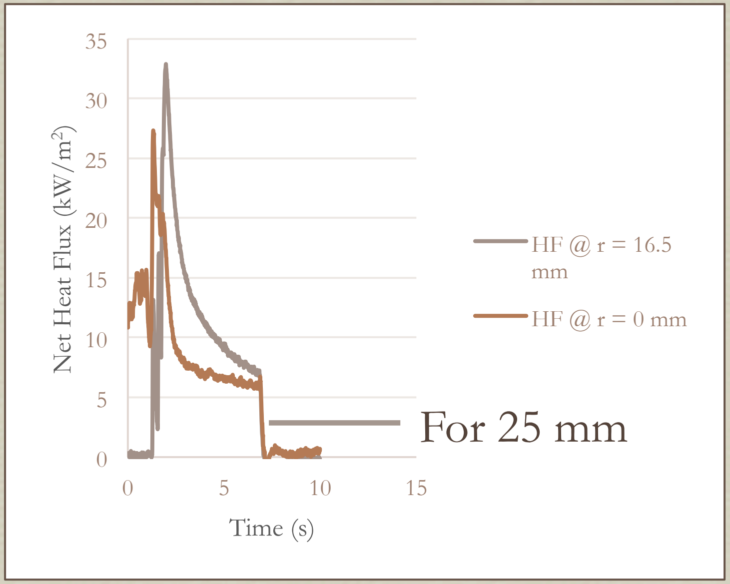
Ignition 0.5s
Before 0 g

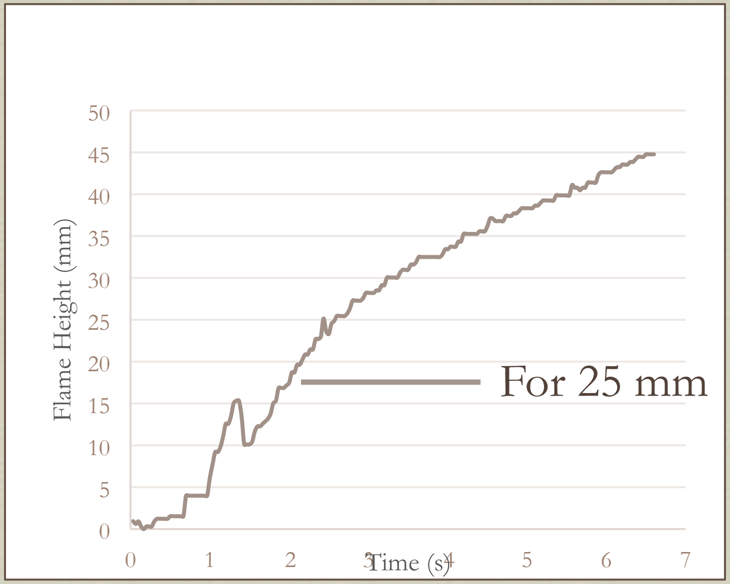


Steady at End?

Test 92 - C_2H_4 - 50 mm - 30% O_2 - 0.7 atm – compared to C_2H_4 - 25 mm - 30% O_2 - 0.7 atm

- **25 mm heat flux ~ 3 kW/m²; 50 mm ~ 7 kW/m²**





- **Think radiation from gases is increasing with diameter**

Analysis

- BRE gives surface temperature and net heat flux
- Compute heat of gasification $\dot{m}''L = \dot{q}''_{net}$
- Obtain **"steady burning"?**
- **Diffusive theory**
  - **Heat flux** $\dot{q}''Dc_p / kL = \left(\dfrac{8}{\pi}\right)\ln(1 + \dfrac{Y_{ox,\infty}\Delta h_{c,ox}}{L})$
  - **"Height"**

$$\frac{y_f}{D} \equiv \left(\frac{\pi}{8}\right)\frac{B\ln\left[(1+B)/(Y_{ox,\infty}/(Y_{F,o}\Delta h_c/\Delta h_{ox})+1)\right]}{\left[\ln\left(1+B\right)\right]^2}$$

2-D theory H. Baum

- Conservation of Mass

$$\nabla \cdot (\tilde{\rho}\vec{u}) = 0$$

- Conservation of Energy and Species

$$\nabla \cdot (\tilde{\rho}\vec{u}Z) - \nabla \cdot \left(\tilde{\rho}\tilde{\mathcal{D}}\nabla Z\right) = 0$$

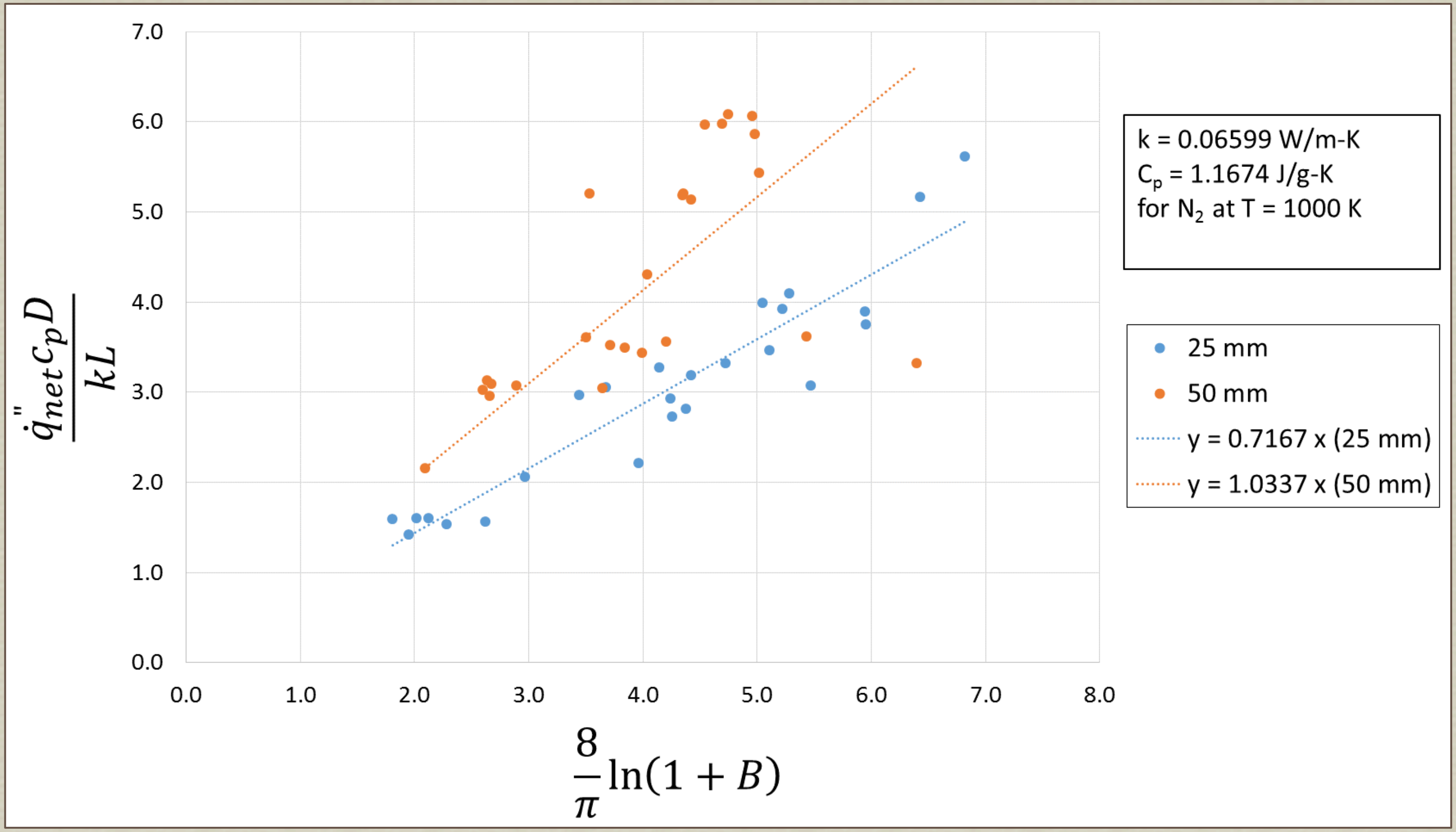
- Potential flow and diffusivity

$$\vec{u} = \nabla\tilde{\phi} \qquad (\tilde{\rho})^n\tilde{\mathcal{D}} = (\tilde{\rho}_\infty)^n\tilde{\mathcal{D}}_\infty$$

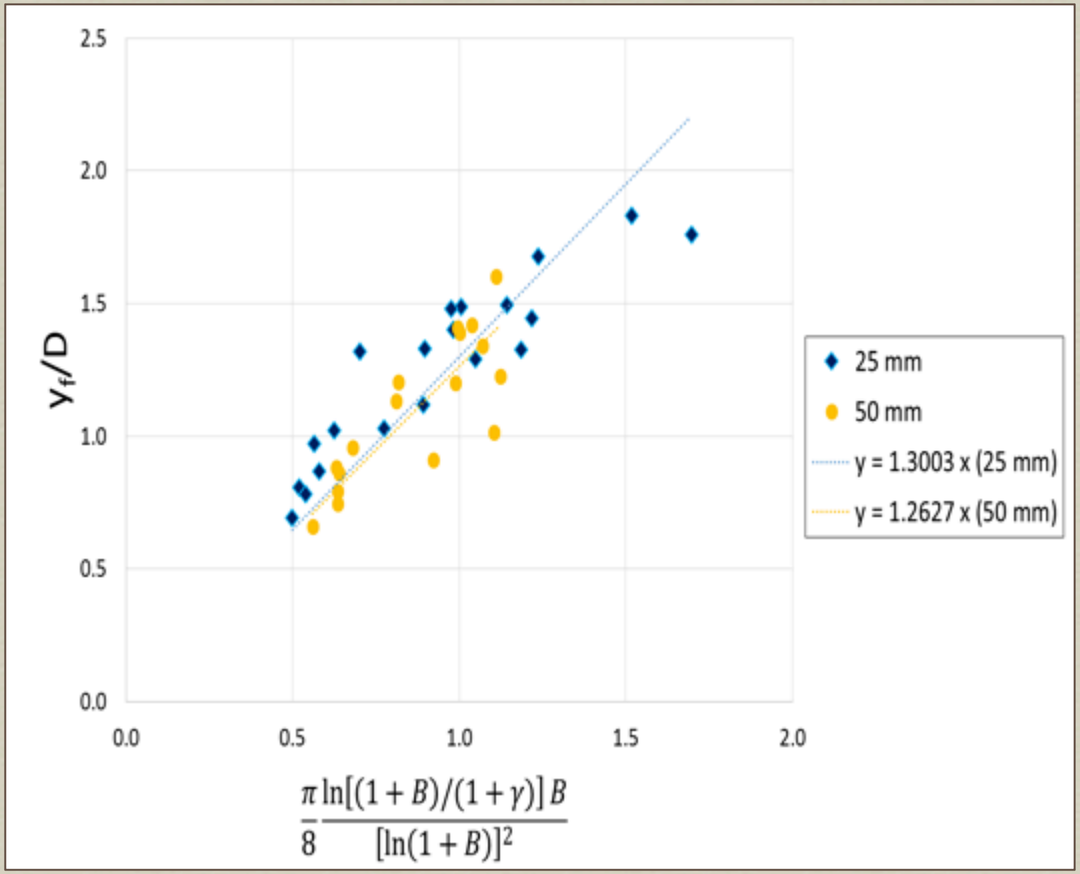
$$\dot{m}'' = \frac{2k}{c_p R}\ln(1+B) / \left(\frac{\pi}{2} - \arctan(\xi_o)\right)$$

Same as 1-D for flat ellipse
But analytic solution for ellipsoidal flame!

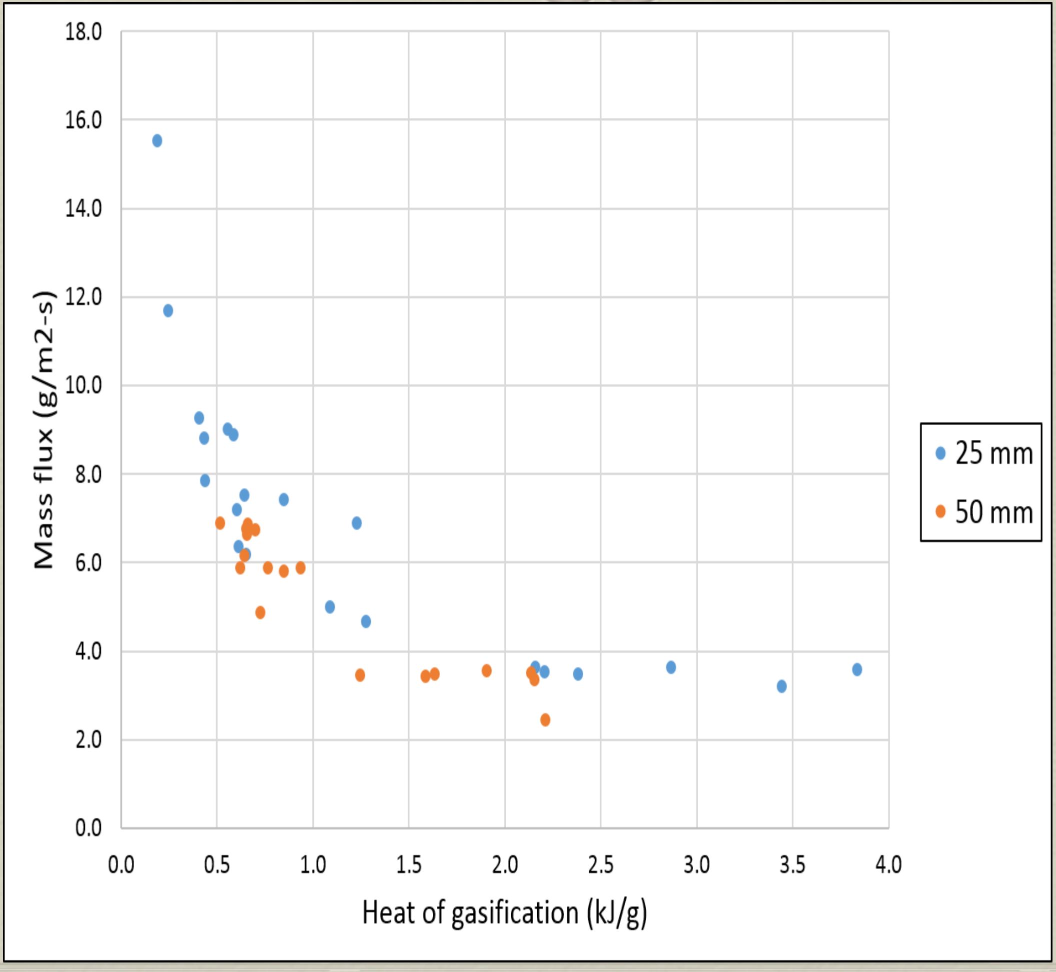
Dimensionless Heat Flux



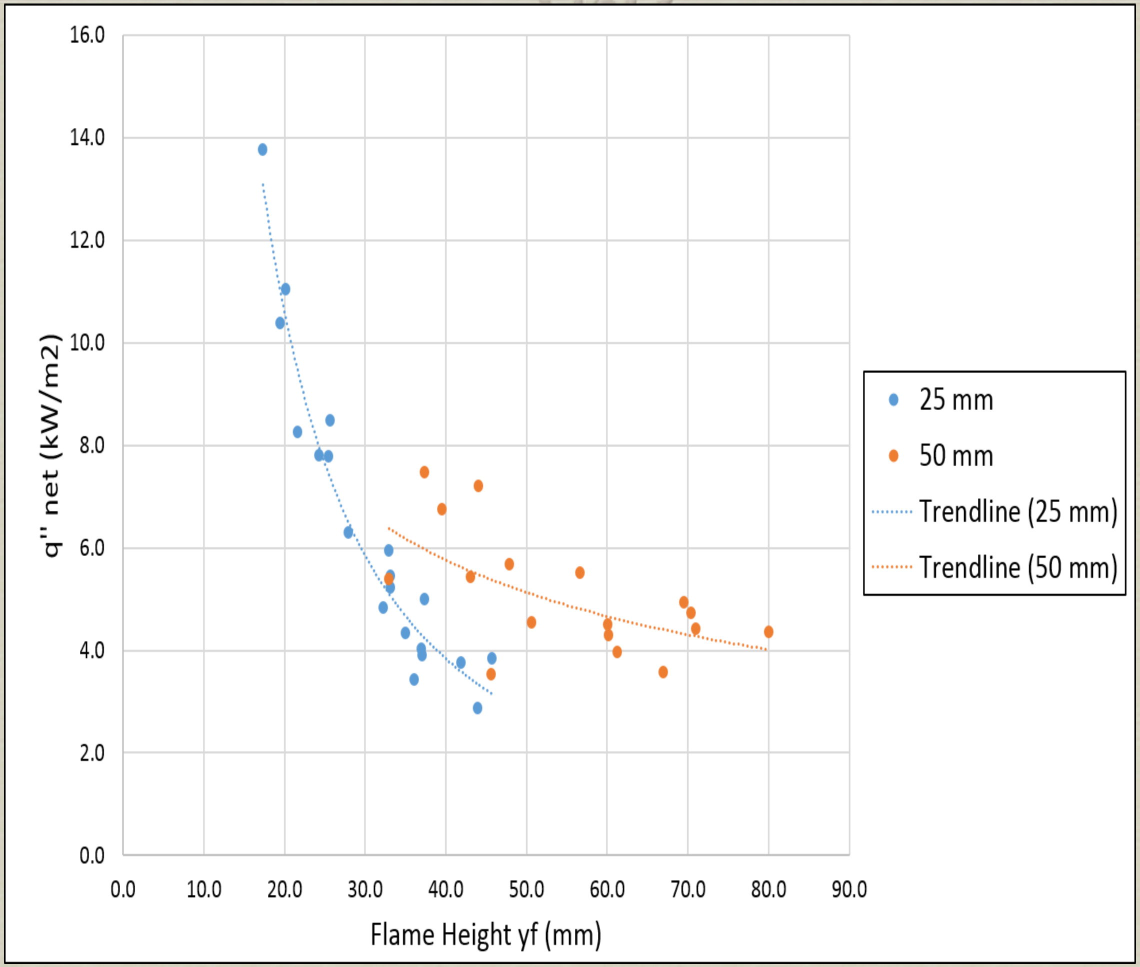
Dimensionless Flame Height



Mass Flux vs L



Radiation for 50 mm

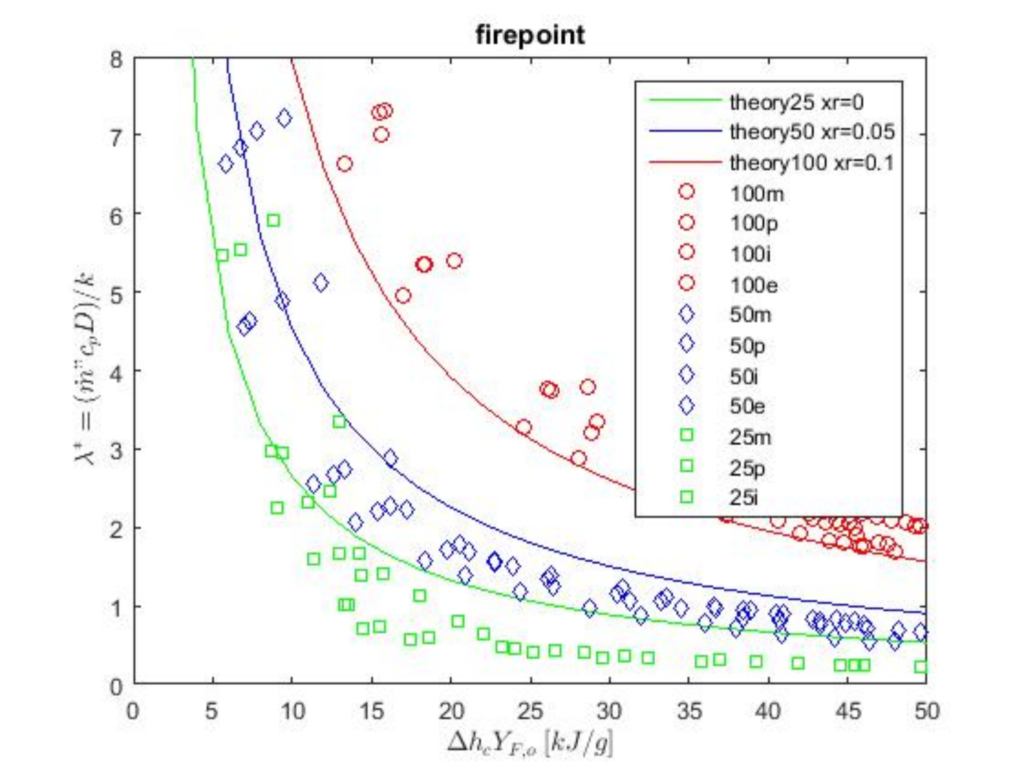


Conclusions

- BRE gives efficient results in microgravity
- "Drop" tests show possible trend toward steady state
- A steady model correlates results over changes in fuel, pressure, oxygen, and flow rate
- Burning and heat flux depend on *L*, heat of gasification and *D*, diameter
- Flame size depends linear on *D*, and on *L* and fuel mass fraction in the BRE flow
- Both also depend on oxygen concentration, but not apparently on pressure (Pressure effects flame height, but not in theory)

Ignition/Extinction in 1g

- PhD student from U of Lund



Future

- Explore Baum 2-D solution (& extinction)
- Compute gas radiation
- Add radiation (analytic and numerical)
- Explore 1-g BRE
- Calibrate NASA BRE burners
- Attempting new PhD student by NASA student grant